Optical diagnostics for warm dense matter experiments at NDCX-I/II

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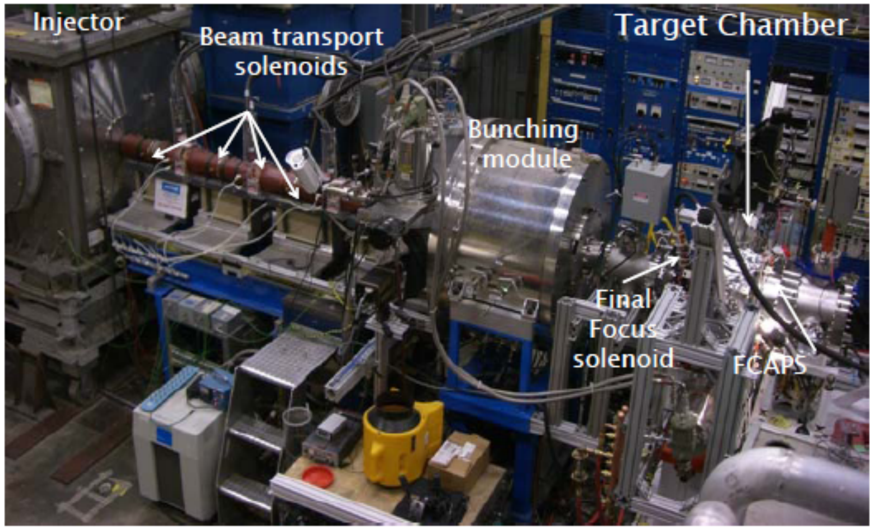
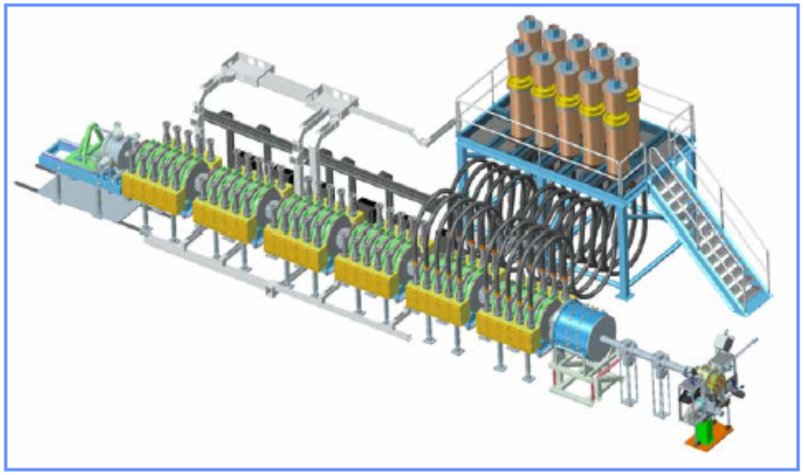
NDCX I is laying the groundwork for NDCX II.

NDCX I
0.35 MeV,
0.003 μC
2 ns
Now



- Explore liquid/vapor boundaries at T ~ 0.4 eV
- Evaporation rates/ bubble and droplet formation
- Test beam compression physics
- Develop diagnostics

NDCX II
3 - 6 MeV,
0.03 μC
1 ns
Completion date: 2011

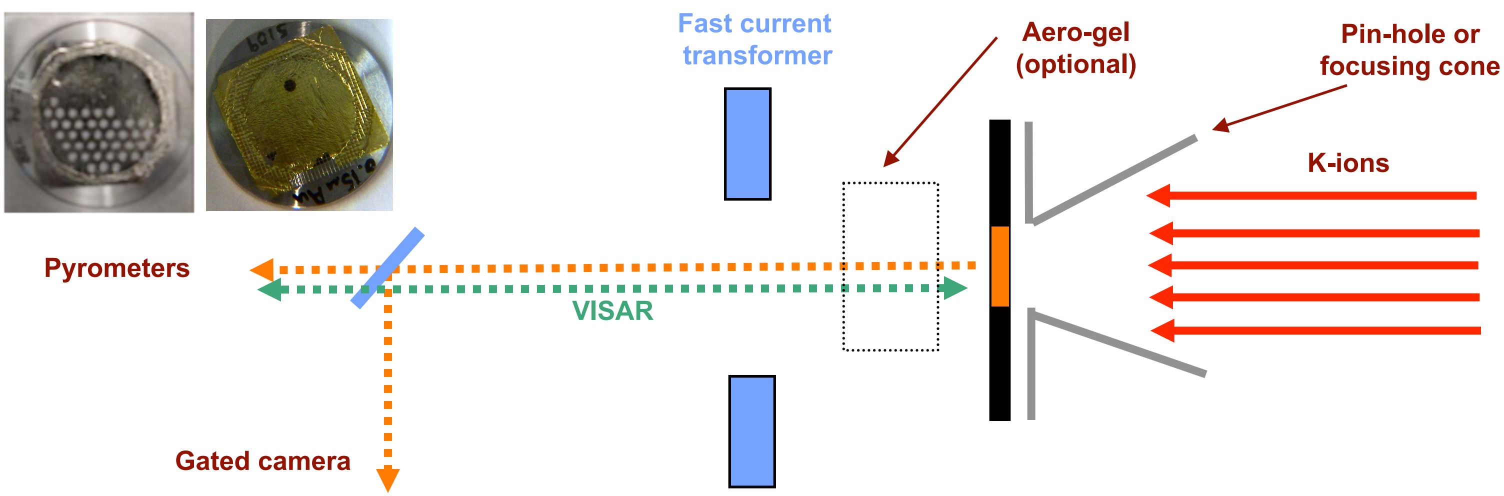


- Bragg peak heating
- T ~1-2 eV in planar targets (higher in cylindrical/spherical Implosions)
- Ion$^+$/Ion$^-$ plasmas
- Critical point; complete liquid/ vapor boundary
- Transport physics
- HIF coupling and beam physics

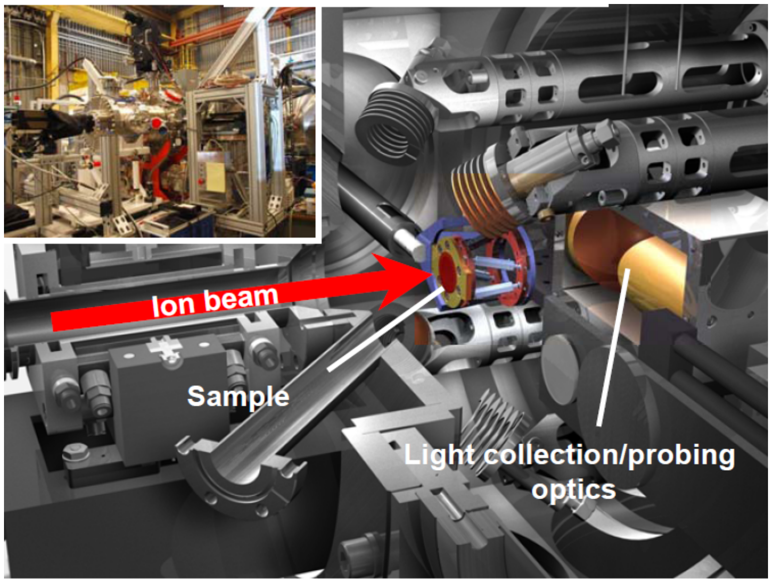
List of diagnostics

Diagnostic:	Measures:	Status:
Fast multi-channels pyrometer	Black body temperature	Fielded
Streak-pyrometer	Temperature	Fielded
Doppler-shift interferometer	Surface expansion velocity, pressure	In progress
Gated amplified CCD cameras	Sample Instant imaging	Fielded
Current transformer	Ion beam transmission, density	Fielded
Polarization pyrometer	Temperature	R&D in progress
Microscope imaging	Droplet formation imaging	In progress
X-pinch	Density	Planned in 2011
Polarimeter	Reflectivity/Emissivity/AC conductivity	Planned in 2011
Heterodyne interferometer	Low, Plasma density	Planned in 2012
Electrical conductivity	Target breaking, droplet formation	After 2012
Thomson Scattering	Temperature and more	NDCX-II

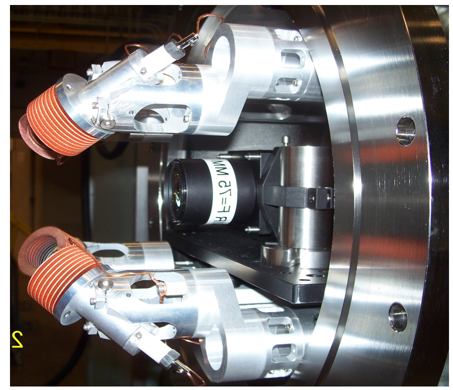
Experimental setup



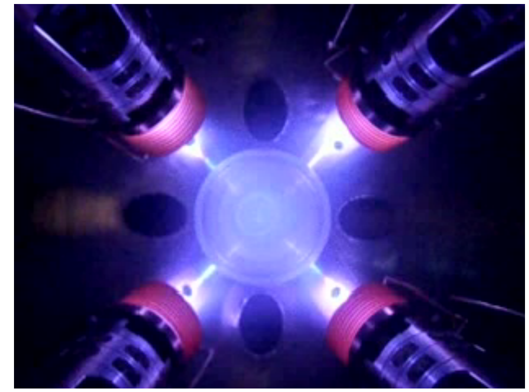
Target chamber area



Probing optics inside chamber

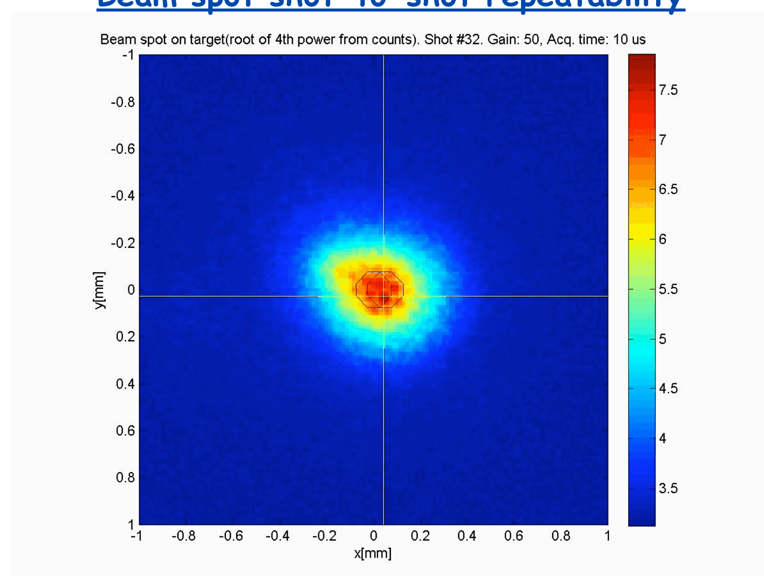


Neutralization plasma

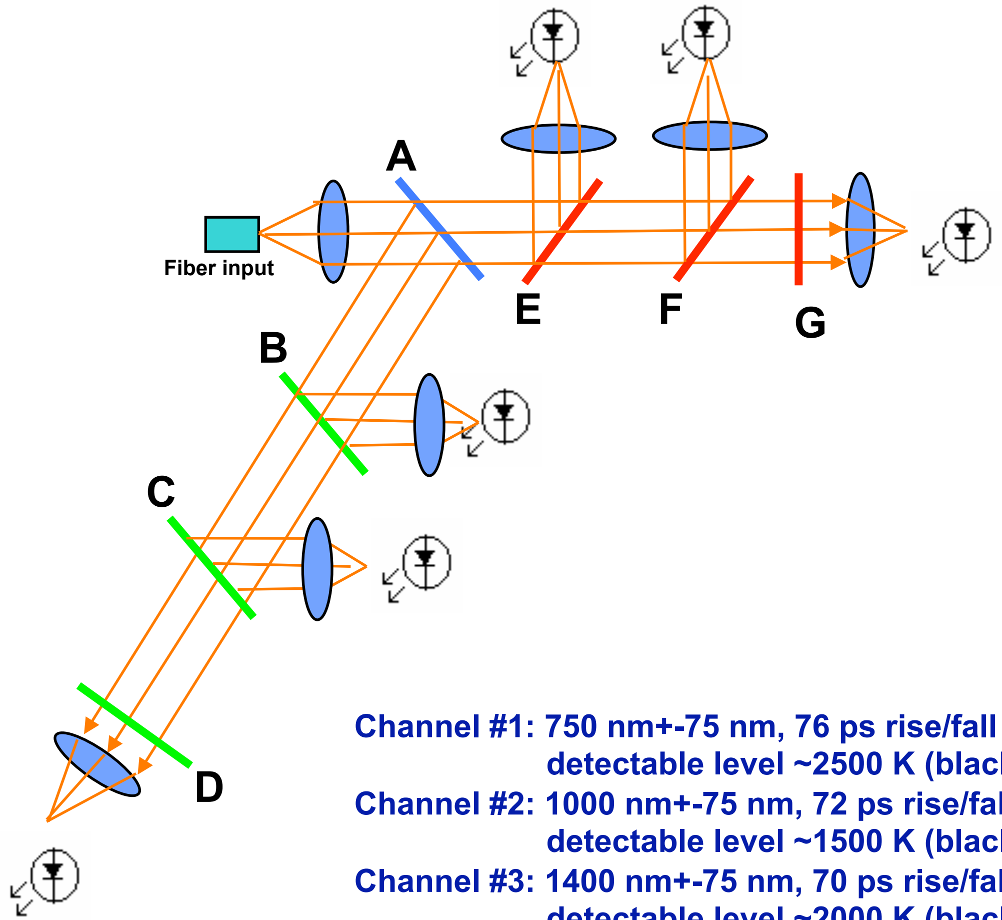


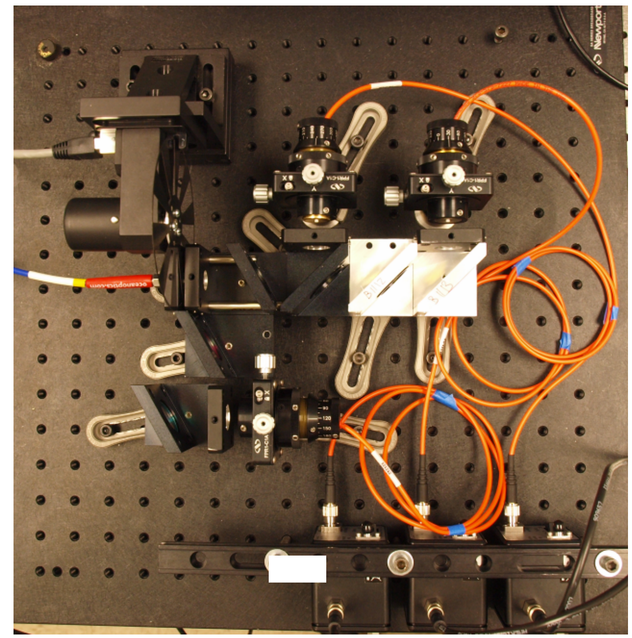
Target holder area during shot

Beam spot shot-to-shot repeatability



Sub-ns optical pyrometer for experiments at NDCX-1



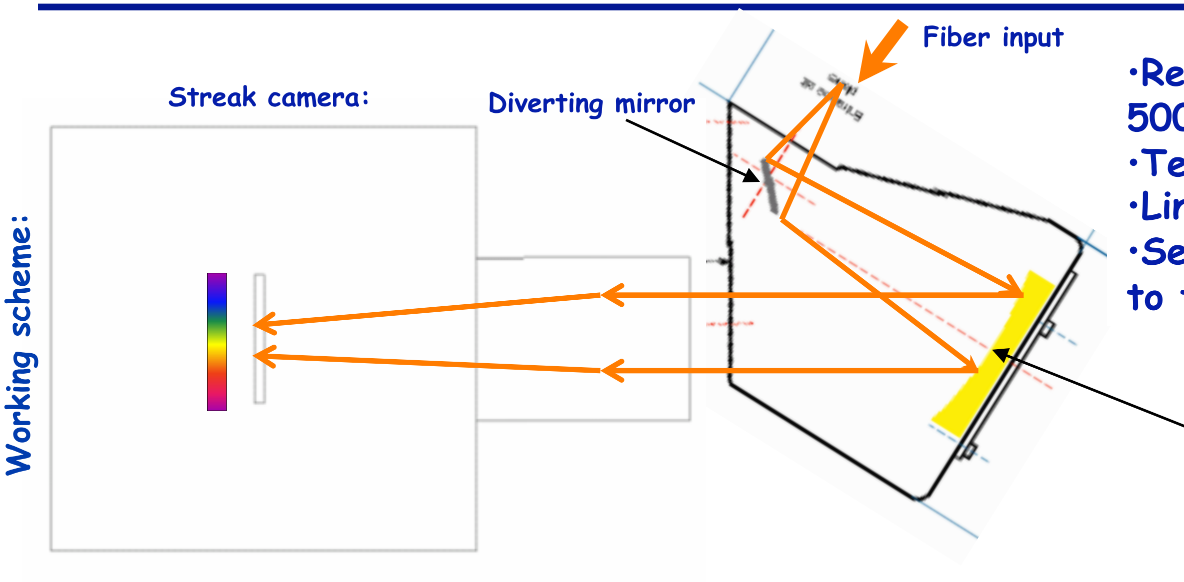


Channel #1: 750 nm+-75 nm, 76 ps rise/fall time
detectable level ~2500 K (blackbody)
Channel #2: 1000 nm+-75 nm, 72 ps rise/fall time
detectable level ~1500 K (blackbody)
Channel #3: 1400 nm+-75 nm, 70 ps rise/fall time
detectable level ~2000 K (blackbody)

•Can be upgraded up to 7 channels

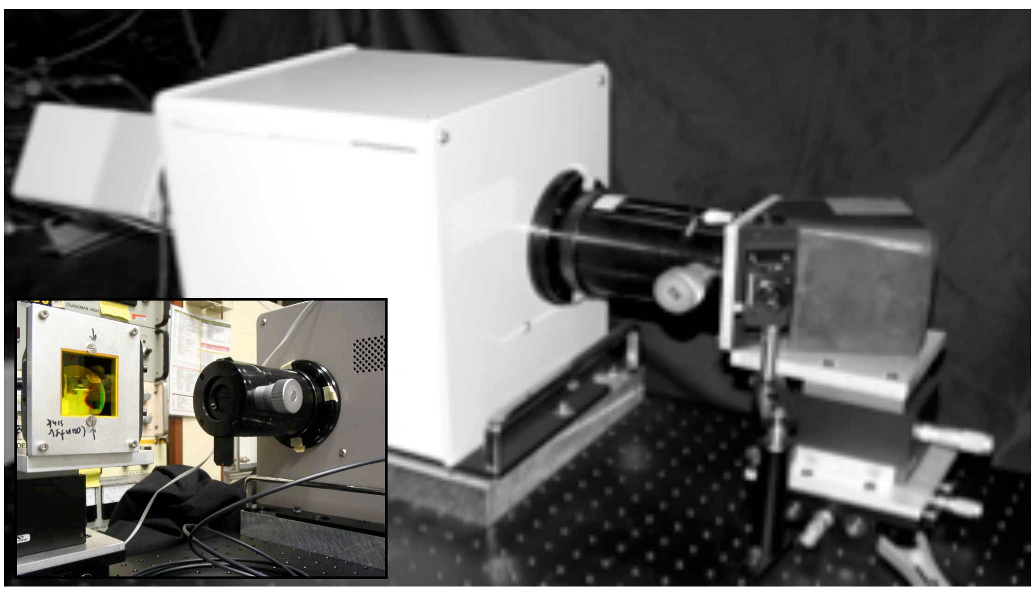
Streak camera for time resolved absolute spectroscopy

Working scheme:

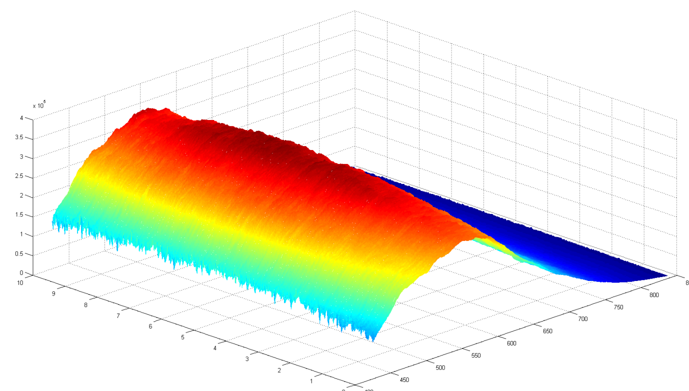


- Records continuous spectrum from 500 nm to 850 nm
- Temporal resolution down to 5 ps
- Linear response
- Sensitivity is inversely proportional to temporal resolution

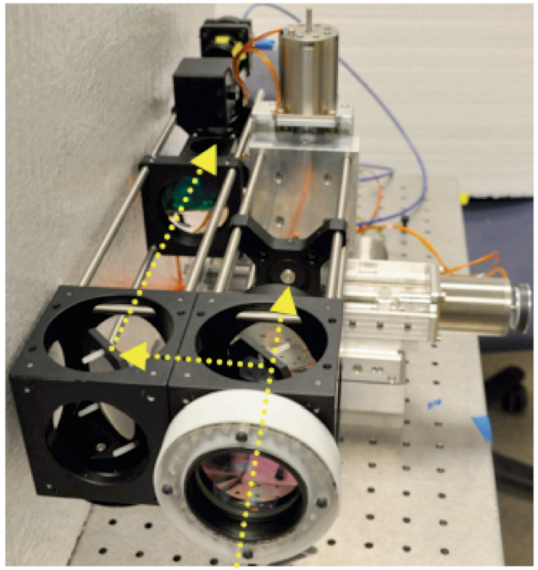
Implementation:

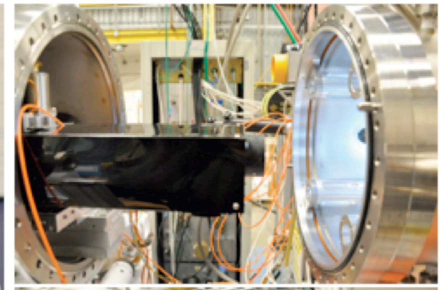


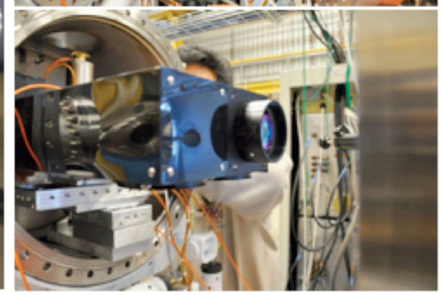
Calibration image of streak camera:



Collection of thermal emission for temperature measurements

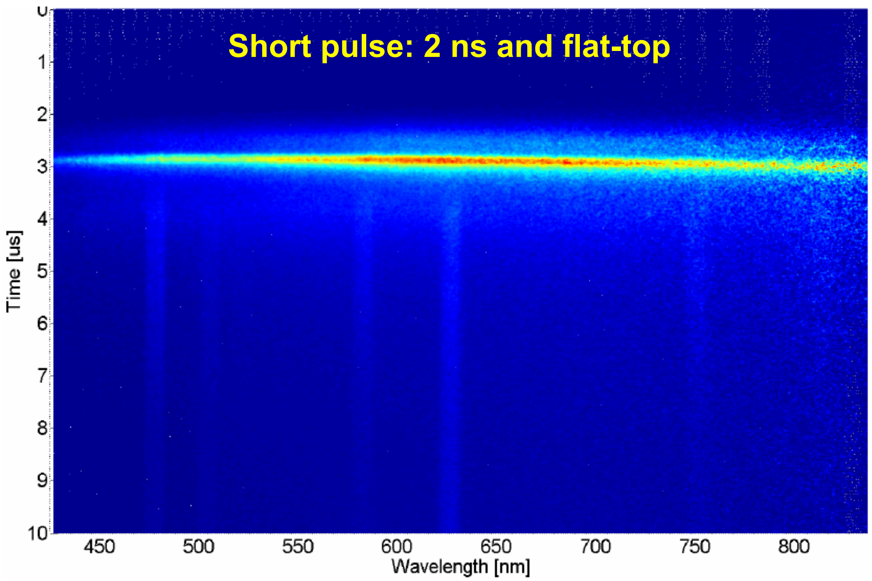


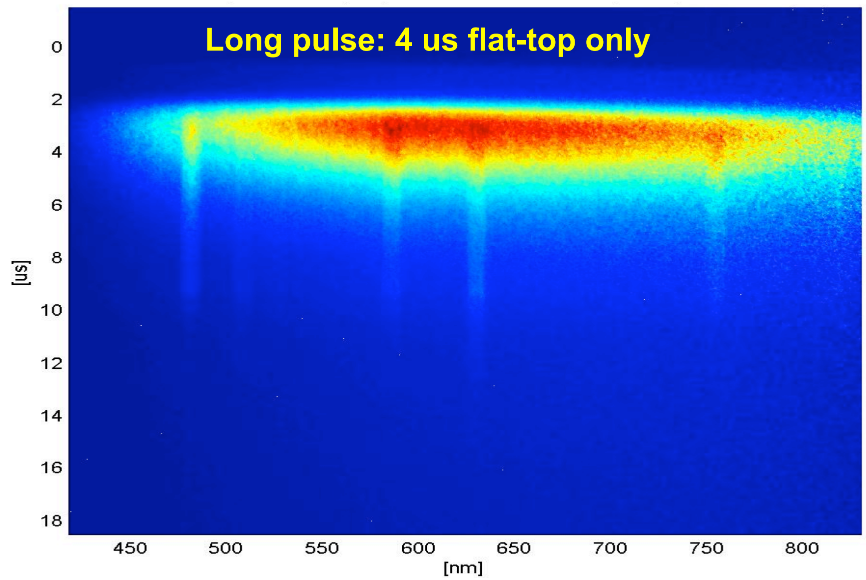




- Simultaneous usage of the streak-camera-spectrometer and the pyrometer.
- VIS (*430 nm to 950 nm*) coupled to streak spectrometer
- NIR (*950 nm to 2000 nm*) coupled to pyrometer
- Complete motorization for precise alignment in vacuum
- Pending integration of visar

Two modes of heating a target

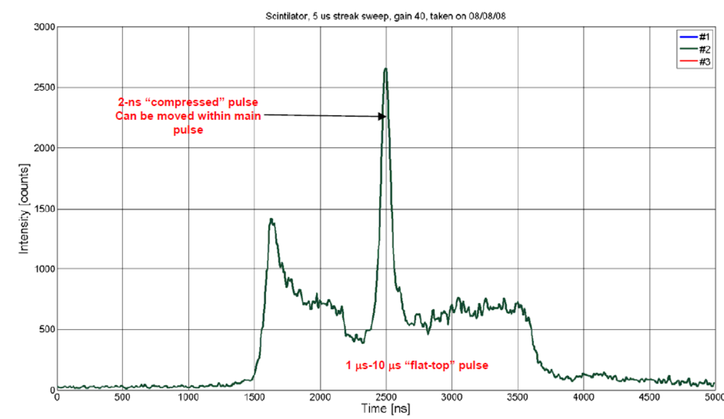




Beam current structure:

- Main, flat-top 1 μs pulse (variable up to 50 μs) with flux on target ~100 mJ/cm2/μs
- Bunch-compressed 2-ns pulse with flux ~10 mJ/cm2.
- The compressed pulse can be delivered controllably at any time within the duration of the main pulse.

NDCX-1 beam pulse structure

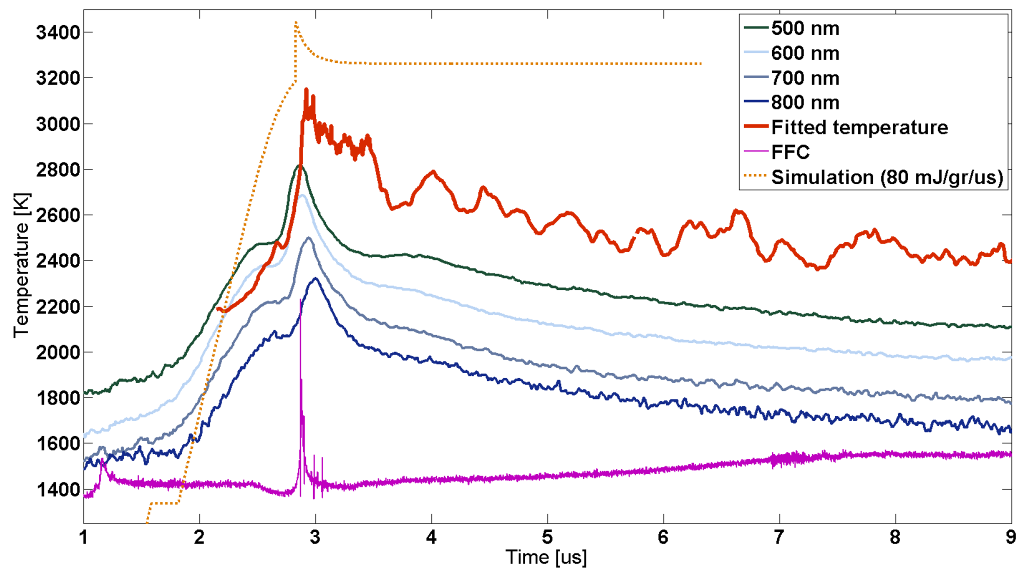


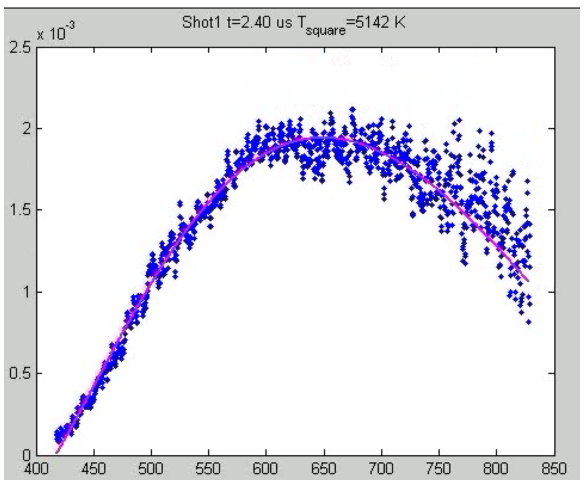
Temperatures reconstucted from streak camera data: Au

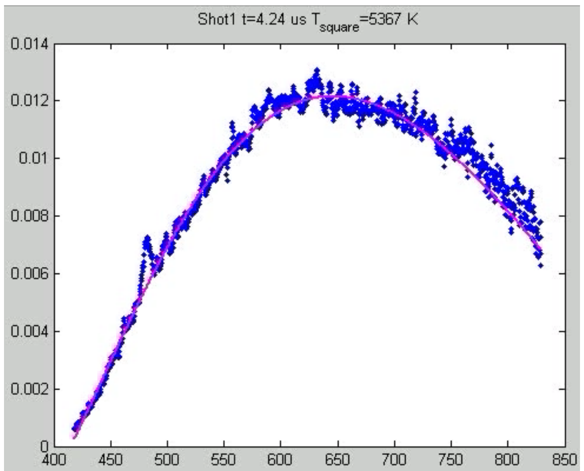
$$I(\lambda, T) = \varepsilon(\lambda) \cdot \frac{C_1}{\lambda^5} \frac{1}{e^{\frac{C_2}{\lambda T}} - 1}$$

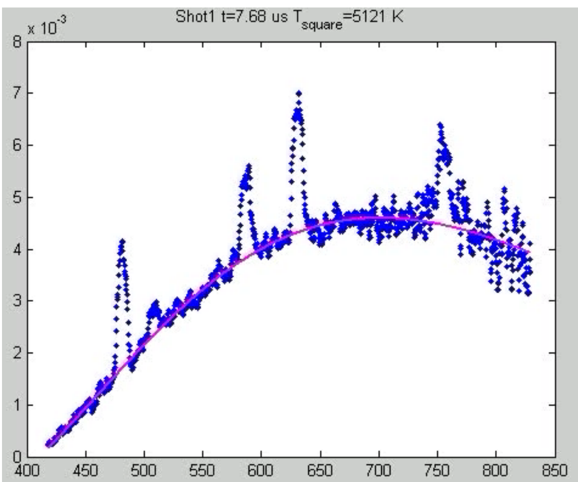
- **Multi-wavelength pyrometery is "ill-posed" problem: n+1 unknowns, n-measured.**

$$\varepsilon(\lambda, T) = A_n(T) \cdot \lambda^n + A_{n-1}(T) \cdot \lambda^{n-1} + \ldots A_0$$



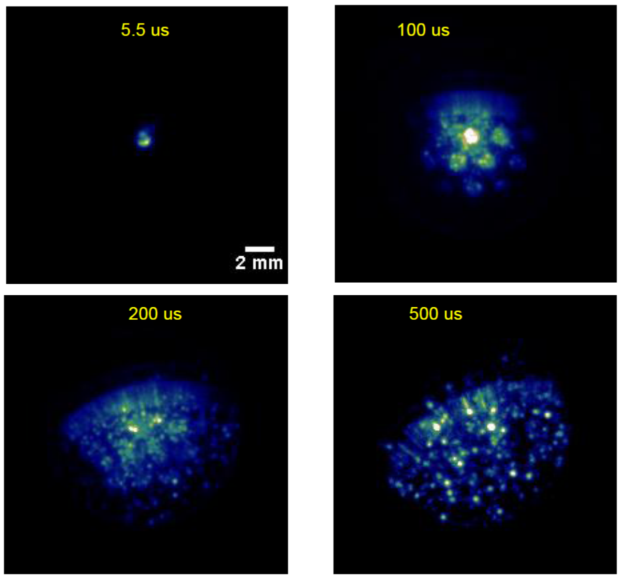


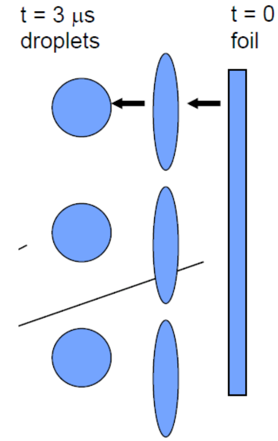


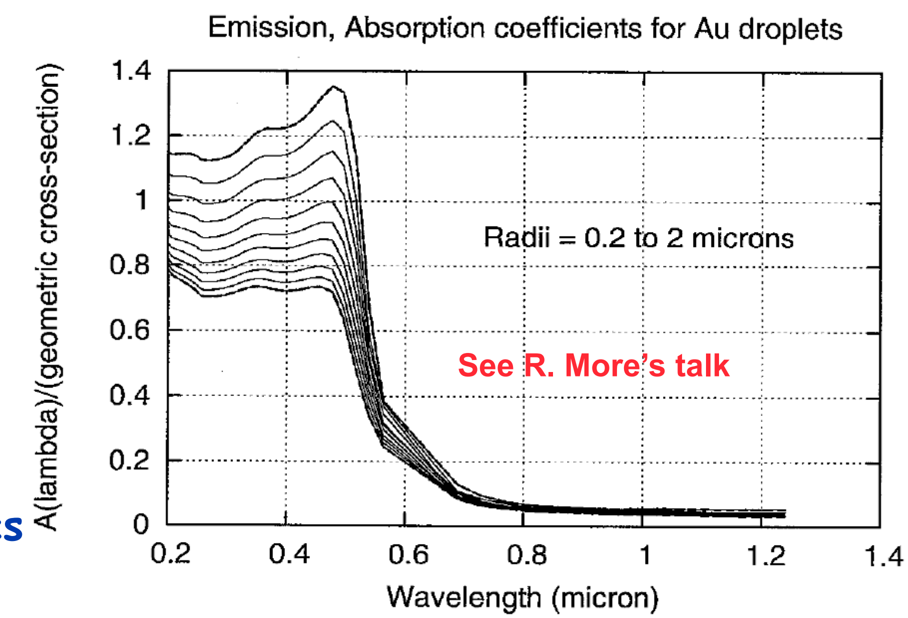


Physics of droplet formation and droplet radiation

Shower of hot debris fragments after end of shot suggests droplet formation.



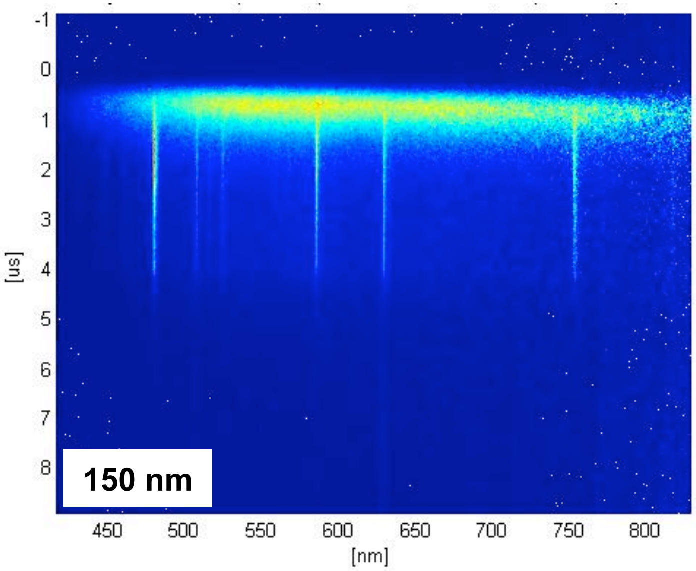


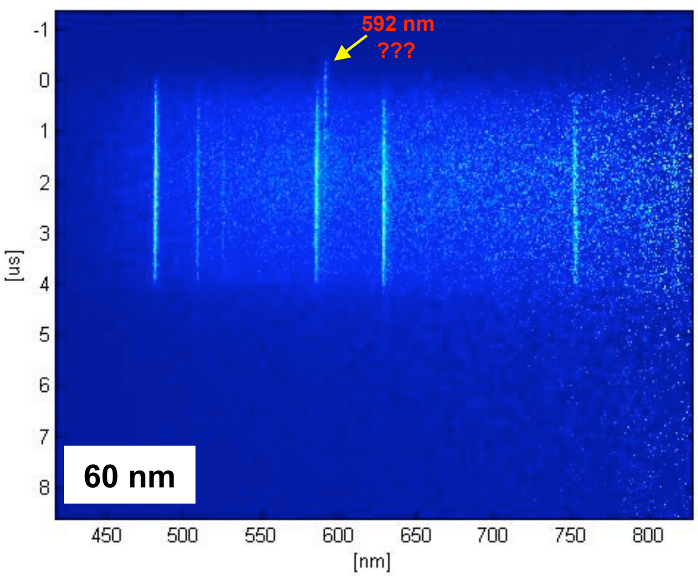


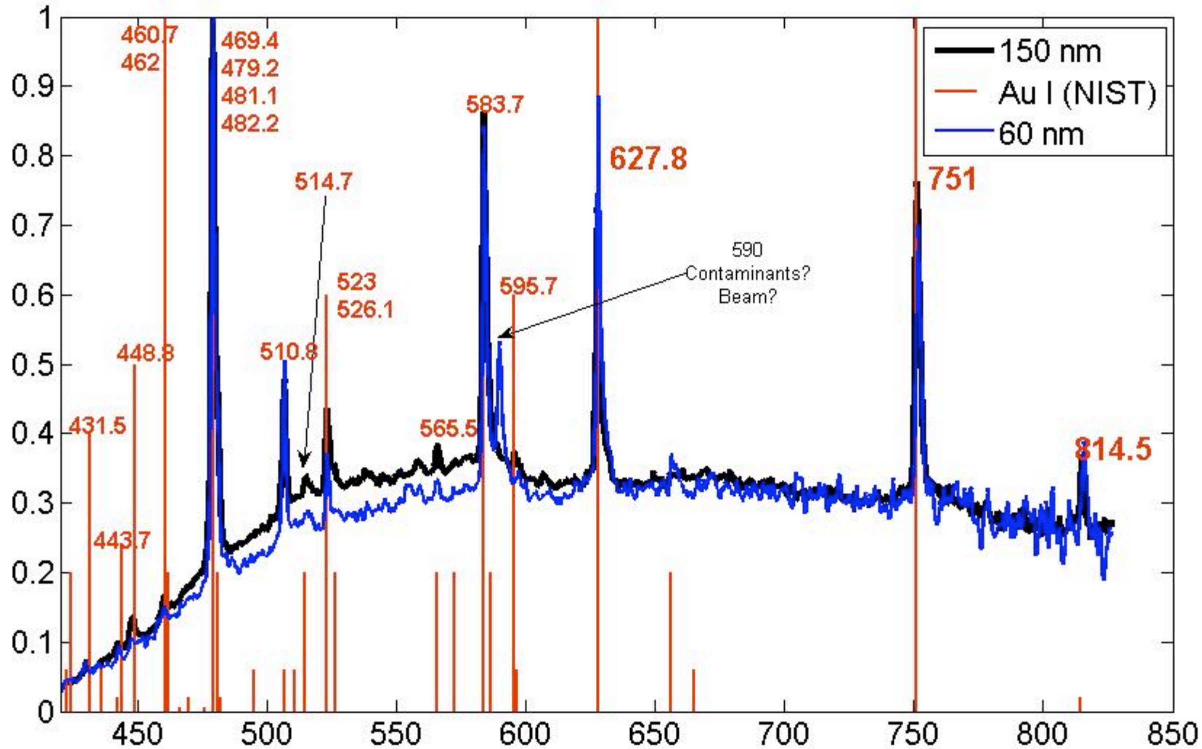
<u>New physics opportunities:</u>

- Physics of droplet formation determined by surface tension, instabilities etc.
- Interpretation of the optical data for gold target based on formation of micron – sized droplets.
- Nano-particles generation and thermodynamics
- Dusty plasma

Unidentified line (592 nm) appears when using thinner targets

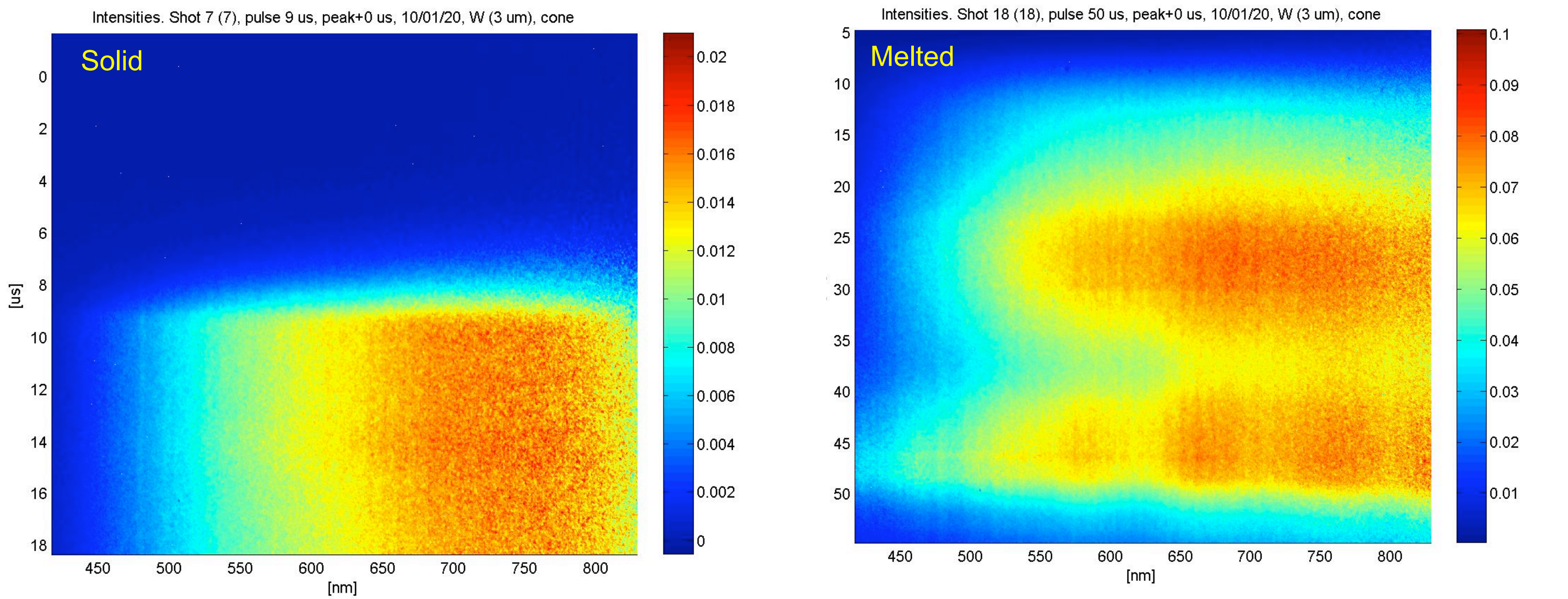






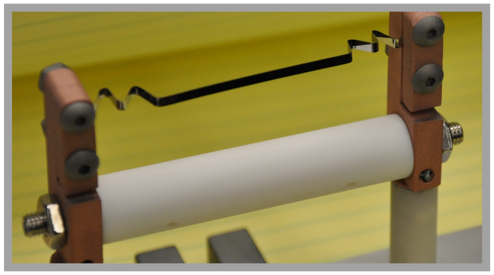
- Streak - spectrometer data in Au target showing transition from continuum emission to emission lines from heated gold
- All but one line are identified as Au I. This line is neither Au, K, Ni, O nor H
- What physics is behind this line?

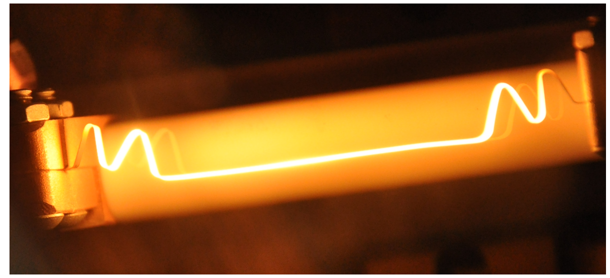
Spectra of melting tungsten



- Thermal emission modulated by changing emissivity (dielectric coefficient)
- Simple polynomial models of emissivity do not work
- Studies of optical properties during phase transitions

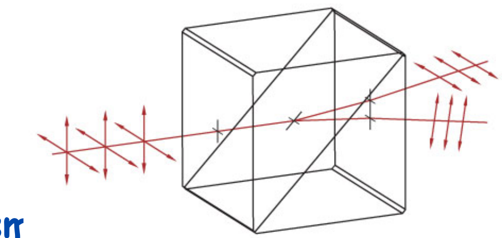
Thermal self-emission of hot metals is polarized



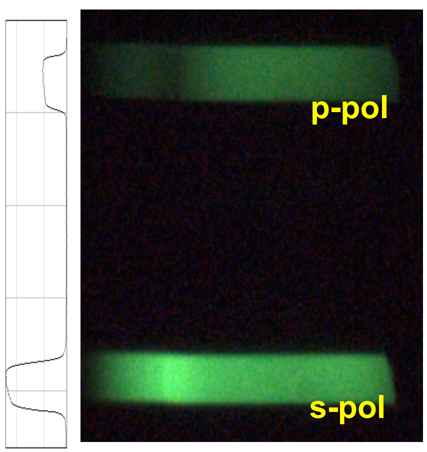


In 2009 R. More suggested to:

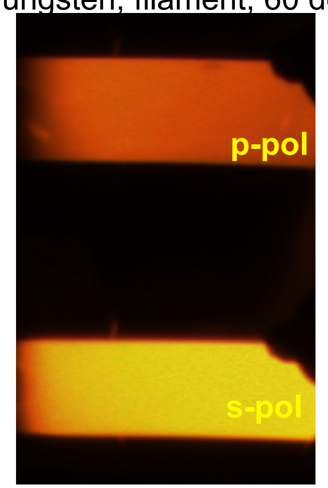
- Heat up plane metal filament with current
- Looking at it under an angle
- Compare P- and S- components of self-emission
- As a first attempt we took a ccd camera with a built in Wollaston-prism



Molybdenum filament, 45 deg, 530 nm

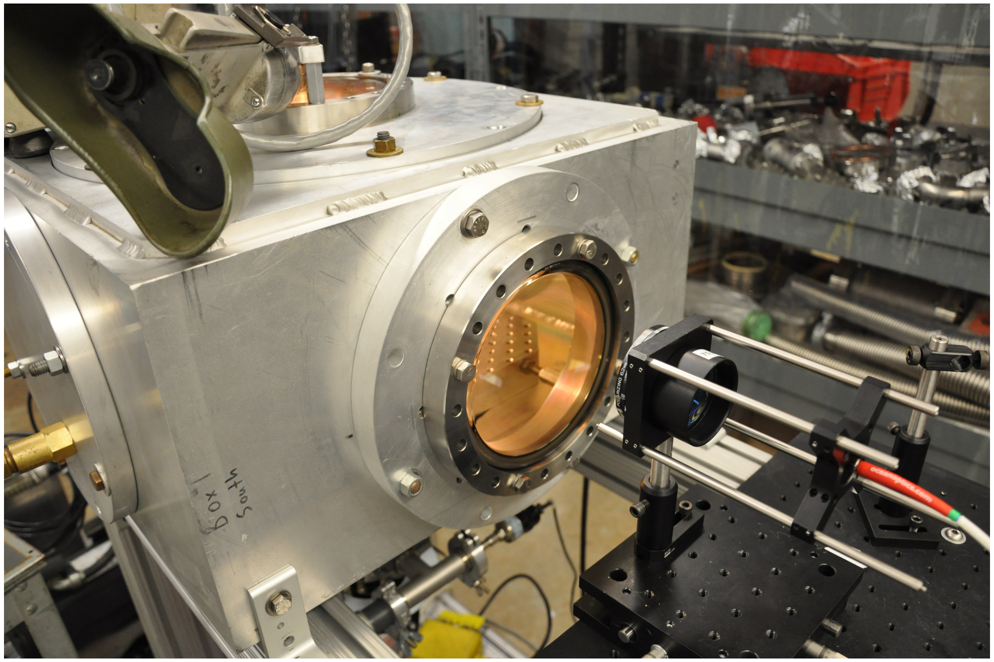


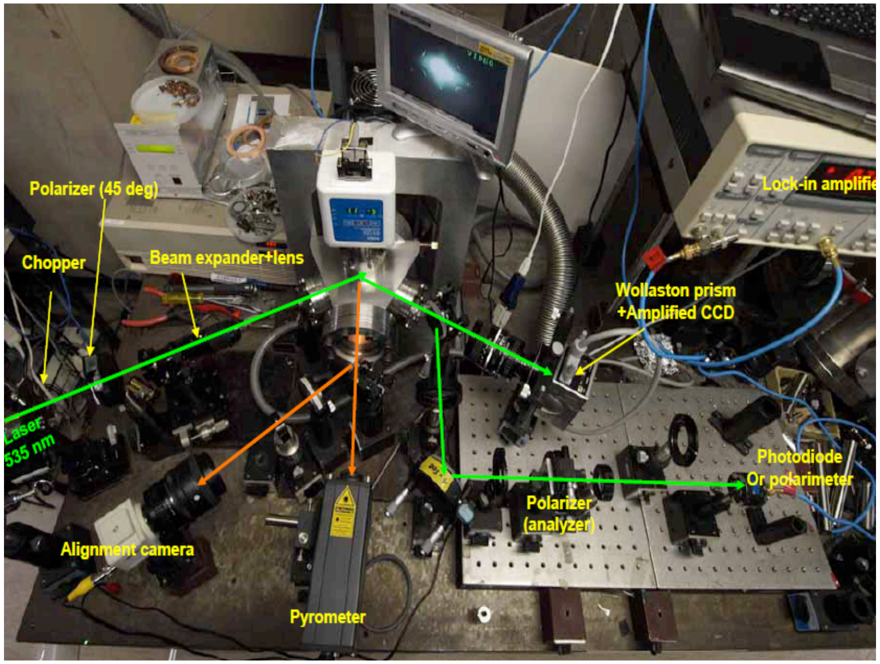
Tungsten, filament, 60 deg



Similar effects were detected with W, Mo, Pt, Ta, Mo-Re

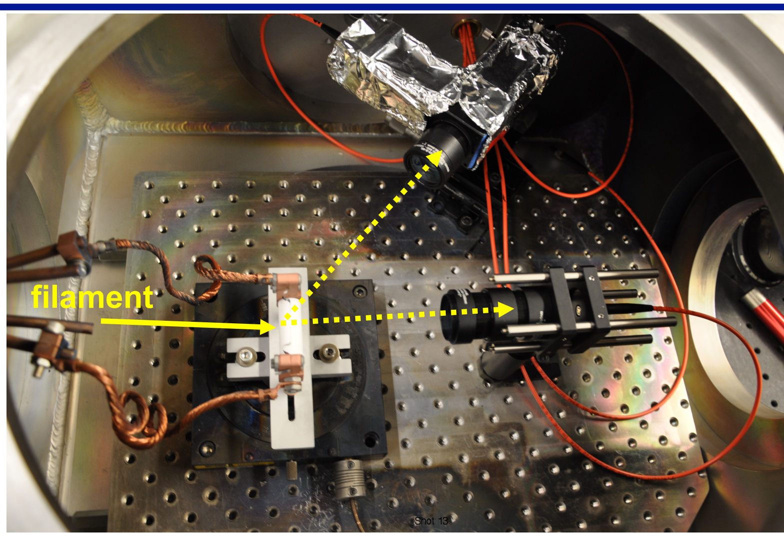
Experiments in LBNL and Tokyo



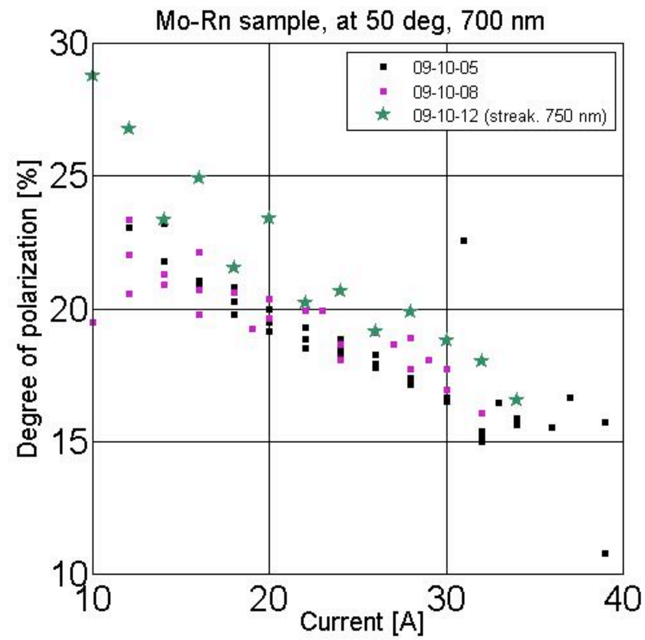


Degree of polarization (DOP) of Mo-Re

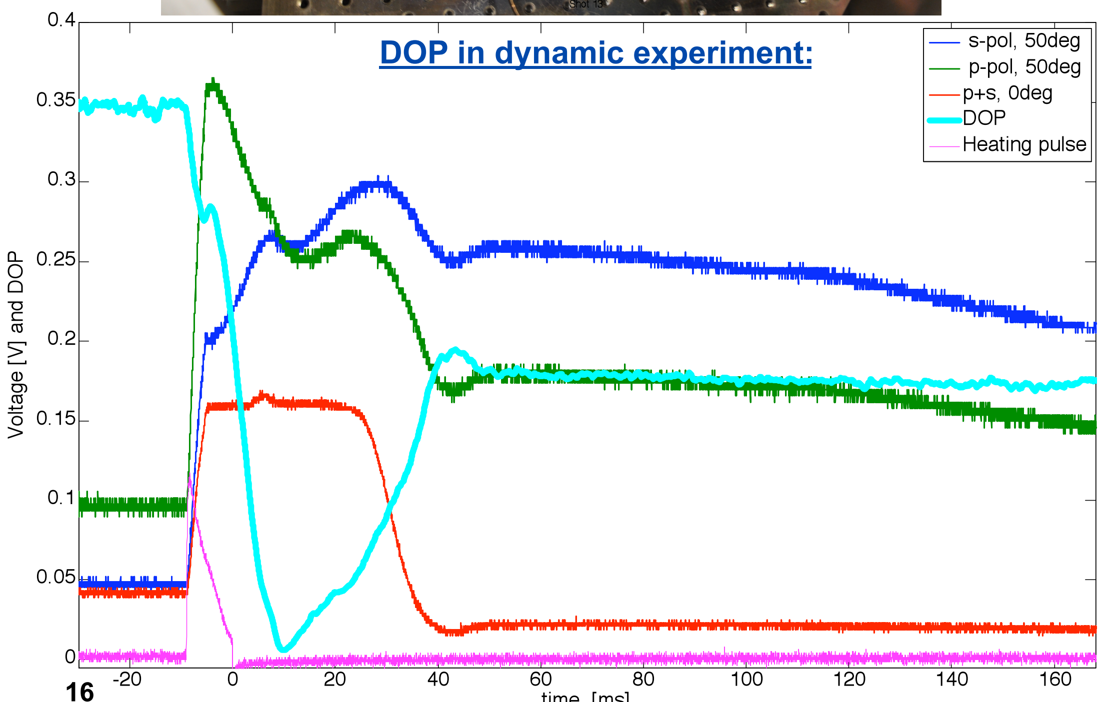
Setup:



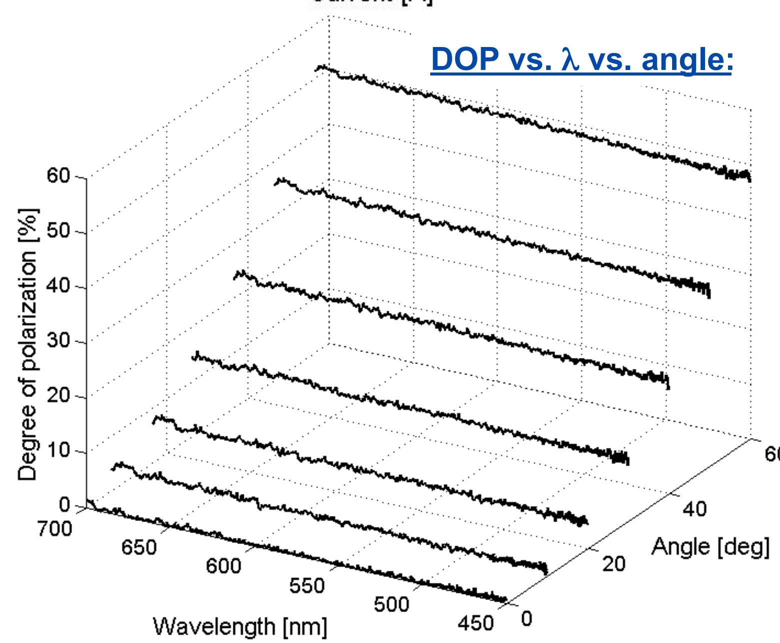
DOP vs T:



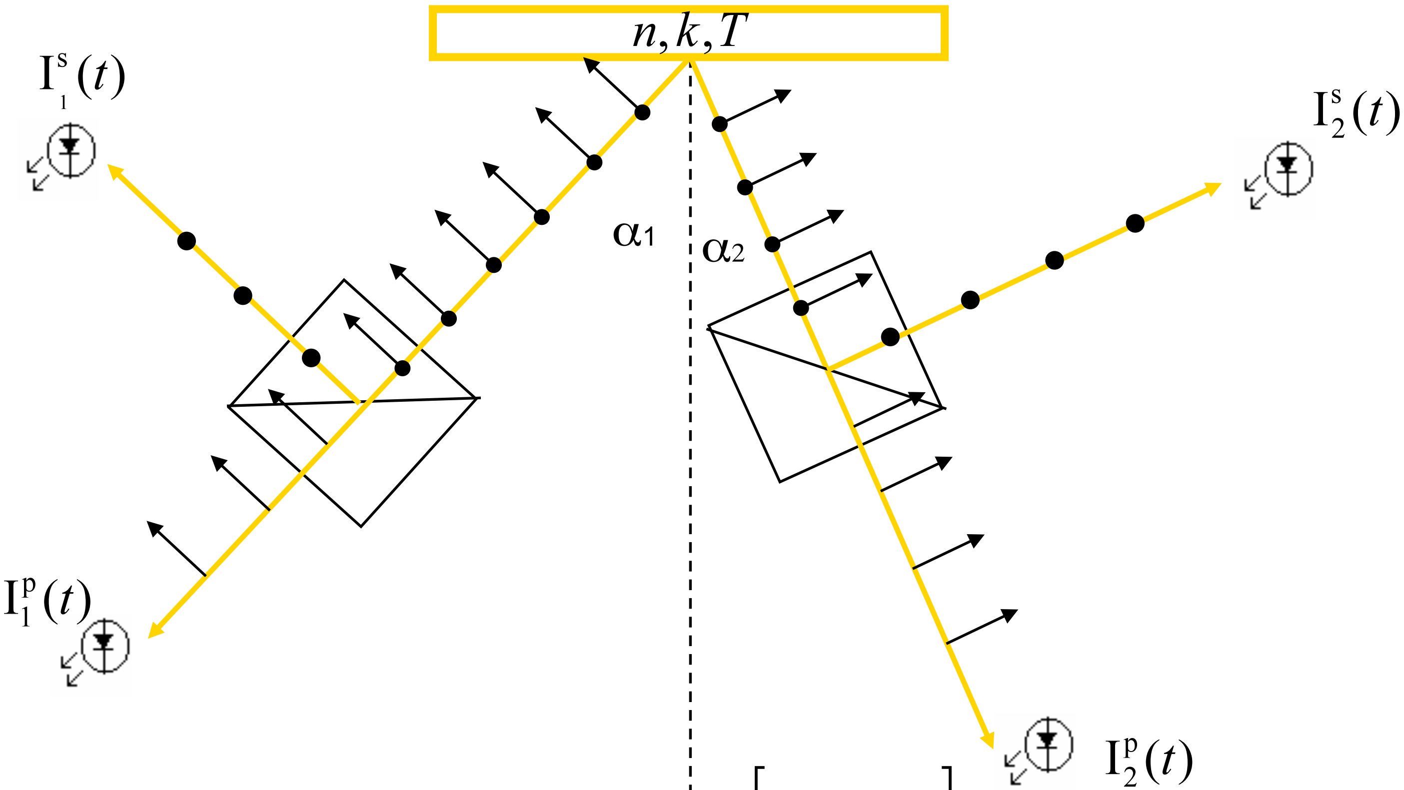
DOP in dynamic experiment:



DOP vs. λ vs. angle:



A new approach to measure temperature



Radiation at each detector : $I_i^{p,s} = \left[1 - r_{p,s}(n,k,\alpha_i,\lambda)\right] \times \left[\frac{C_1}{\lambda^5}\frac{1}{e^{\frac{C_2}{\lambda T}}-1}\right],\ i = 1, 2,$

where $r_{p,s}$ are Fresnel forumalas of reflectivity.

We have three unknowns, n, k, T and four knowns, $I_i^{p,s}$. If surface is desribed by Fresnel forumals we can uniqely extract temperature!

In generall case a code is being developed (R. More)

Summary

•We now have necessary minimum to begin with WDM studies. More diagnostics are on the way.

•NDCX-I is a test ground, real discoveries will be made at NDCX-II

•Even in initial NDCX-I experiments, we discovered new and rich physics

•Future experiments with NDCX-I and NDCX-II will explore aspects of WDM physics including high electron affinity targets, porous targets, cylindrical/spherical implosions, beam-target coupling, etc.

•Diagnostics wish list from users